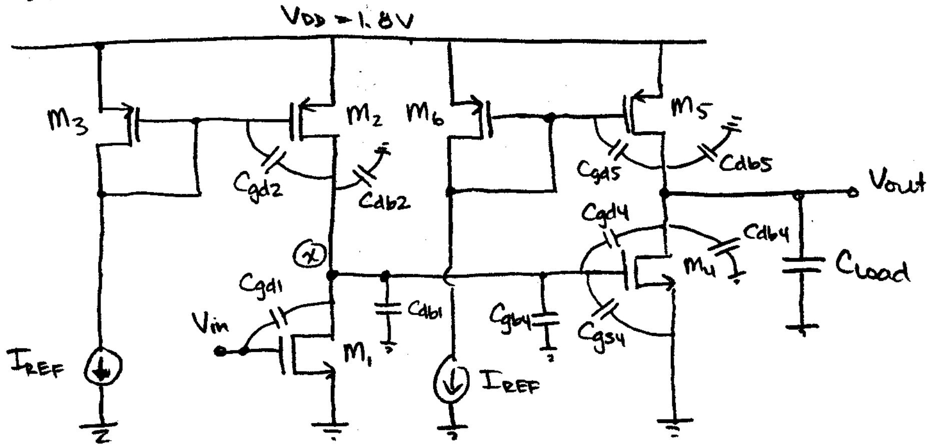
Homework 5, Fall 2004

1) All $W/L = 2/0.18$, $V_{DD} = 1.8V$, $I_{REF} = 10\mu A$. Assume wells of all devices are tied to their respective sources. DC voltage at Vin is set to bias Vout at 0.9 V.



a) The two poles will be associated with node x and the output. There is no pole associated with the input because there is no source resistance.

The resistance at node x is: $R_x = r_{o1} \| r_{o2} = \frac{1}{\lambda_n I_{DS}} \| \frac{1}{\lambda_p I_{DS}}$

$$\boxed{R_x = 400\,k\Omega}$$

The resistance at node Vout is: $R_{out} = r_{o4} \| r_{o5} = \boxed{400\,k\Omega}$

For all transistors:

$$C_{gd} = C_{gdo} \cdot W = (5\times10^{-10})(2\times10^{-6}) = \boxed{1\,fF}$$
$$C_{gb} = C_{gbo} \cdot L = (4\times10^{-10})(0.18\times10^{-6}) = \boxed{0.072\,fF}$$
$$C_{gs} = C_{gso} \cdot W + \frac{2}{3} C_{ox} WL = \boxed{4.36\,fF}$$

We assume that the source and drain regions are minimum size and have a length of $4\lambda = 4(0.09\mu m) = 0.36\mu m$.

Thus, area of source/drain $= 4\lambda \cdot W = \boxed{0.72\,\mu m^2}$
perimeter of source/drain $= 8\lambda + W = \boxed{2.72\,\mu m}$

The voltage at node x is: $V_x = V_T + V_{DSAT} = 0.5 + \sqrt{\frac{2(10)}{140(2/0.18)}} = \boxed{0.613V}$

So, $$C_{db1} = \frac{CJ \cdot AD}{\left(1 + \frac{V_{DB}}{PB}\right)^{mJ}} + \frac{CJSW \cdot PS}{\left(1 + \frac{V_{DB}}{PB}\right)^{mJSW}}$$

$$= \frac{(6\times10^{-4})(0.72\times(10^{-6})^2)}{\left(1 + \frac{0.613}{0.8}\right)^{1/2}} + \frac{(2\times10^{-10})(2.72\times10^{-6})}{\left(1 + \frac{0.613}{0.8}\right)^{1/3}} = \boxed{0.775\,fF}$$

$$\boxed{C_{db2} = 0.676\,fF}$$

1) a) (cont.)

The voltage at $V_{out} = 0.9V$.
Thus,

$$C_{db4} = C_{db5} = \boxed{0.719\ fF}$$

From the sizes of these capacitors, we see that the dominant pole is located at node x due to the Miller capacitance.

The equivalent capacitance at node x is:

$$\boxed{C_x = C_{gd1} + C_{db1} + C_{gd2} + C_{db2} + C_{gs4} + C_{gb4} + (1+g_m R_{out}) C_{gd4}}$$

$$= 1 + 0.775 + 1 + 0.676 + 4.36 + 0.072 + (1 + (176\mu)(400k))(1)\ fF$$

$$= \boxed{80\ fF}$$

$$\therefore \omega_{p1} = \frac{1}{R_x C_x} = \frac{1}{(400k)(80fF)} = 31.25\ Mrad/s \Rightarrow \boxed{5\ MHz}$$

$$\omega_{p2} = \frac{1}{\frac{1}{g_m}(C_{gd1} + C_{db1} + C_{gd2} + C_{db2} + C_{gb4} + C_{gs4} + C_{db4} + C_{gd5} + C_{db5})}$$

$$= \frac{1}{\left(\frac{1}{176\mu S}\right)(1 + 0.775 + 1 + 0.676 + 0.072 + 4.36 + 0.719 + 1 + 0.719\ fF)}$$

$$= 17\ Grad/s \Rightarrow \boxed{2.7\ GHz}$$

From hand calculations, the poles are at:

$f_{p1} = 5\ MHz$
$f_{p2} = 2.7\ GHz$

From SPICE: $f_{p1} = 4\ MHz$
$f_{p2} = 675\ MHz$

The dominant pole is off due to the error in g_m, r_o caused by the large value for λ.

The nondominant pole is further off because the C_{gd4} is not actually that large, and C_{out} begins to reduce the output impedance causing the Miller cap to have less of an effect.

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1) c) When $C_{LOAD} = 10$ pF, the dominant pole is located at the output.

$$\omega_{p1} = \frac{1}{R_{out} C_{LOAD}} = \frac{1}{(400k)(10pF)} = 250 \text{ krad/s} \Rightarrow \boxed{40 \text{ kHz}}$$

$$\omega_{p2} = \frac{1}{R_x (C_{gd1} + C_{db1} + C_{gd2} + C_{db2} + C_{gb4} + C_{gs4} + C_{gd4})}$$

$$= \frac{1}{(400k)(1 + 0.775 + 1 + 0.676 + 0.072 + 4.36 + 1 \text{ fF})}$$

$$= 281 \text{ Mrad/s} \Rightarrow \boxed{45 \text{ MHz}}$$

From hand calculations: $f_{p1} = 40$ kHz
$f_{p2} = 45$ MHz

From SPICE: $f_{p1} = 36$ kHz
$f_{p2} = 38$ MHz

These values are sufficiently close.

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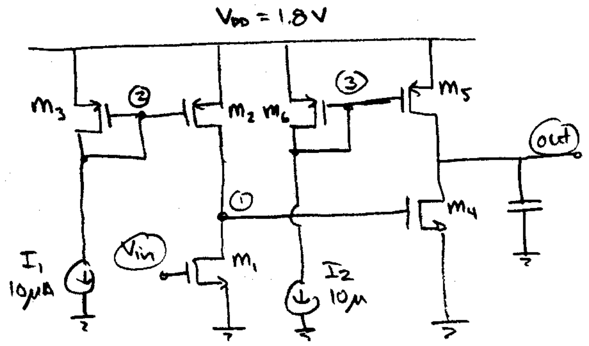
```
* hw8, 1: common-source, common-source amplifier

.model nch nmos level=1 tox=25 vto=0.5 kp=140e-6 lambda=0.1 gamma=0.5 phi=0.6
+capop=0 cgso=5e-10 cgdo=5e-10 cgbo=4e-10 cj=6e-4 cjsw=2e-10

.model pch pmos level=1 tox=25 vto=-0.5 kp=65e-6 lambda=0.15 gamma=0.5 phi=0.6
+capop=0 cgso=5e-10 cgdo=5e-10 cgbo=4e-10 cj=6e-4 cjsw=2e-10
```




```
.param w = 2u
.param l = 0.18u
.param lambda = 0.09u
.param a = '4*lambda*w'
.param p = '8*lambda+w'

vdd     vdd 0 1.8

* set up ac input source
vin     vin 0 0.614 ac 1

m1      1 vin 0 0 nch w=w l=l ad=a pd=p as=a ps=p
m2      1 2 vdd vdd pch w=w l=l ad=a pd=p as=a ps=p
m3      2 2 vdd vdd pch w=w l=l ad=a pd=p as=a ps=p
m4      out 1 0 0 nch w=w l=l ad=a pd=p as=a ps=p
m5      out 3 vdd vdd pch w=w l=l ad=a pd=p as=a ps=p
m6      3 3 vdd vdd pch w=w l=l ad=a pd=p as=a ps=p
i1      2 0 10u
i2      3 0 10u

cload   out 0 0p

.options post=2 nomod captab pztol=1e-4 unwrap

.meas   dc      vbias   find v(vin) when v(out)=0.9

.probe ac vdb(out) vp(out)

.op

.dc     vin 0.613 0.617 0.01m

.pz     v(out) vin

.ac     dec 10 1k 1g

.alter
```

```
 ******  operating point information      tnom=  25.000 temp=  25.000
******
***** operating point status is all       simulation time is     0.
   node     =voltage       node     =voltage       node     =voltage

+0:1        = 610.2628m 0:2        =   1.1412  0:3        =   1.1412
+0:out      = 909.5851m 0:vdd      =   1.8000  0:vin      = 614.0000m


**** mosfets

subckt
element  0:m1       0:m2       0:m3       0:m4       0:m5       0:m6
model    0:nch      0:pch      0:pch      0:nch      0:pch      0:pch
 id        10.7249u  -10.7249u  -10.0000u   10.3162u  -10.3162u  -10.0000u
```

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ibs	0.	0.	0.	0.	0.	0.
ibd	-6.1026f	11.8974f	6.5875f	-9.0959f	8.9041f	6.5875f
vgs	614.0000m	-658.7515m	-658.7515m	610.2628m	-658.7515m	-658.7515m
vds	610.2628m	-1.1897	-658.7515m	909.5851m	-890.4149m	-658.7515m
vbs	0.	0.	0.	0.	0.	0.
vth	500.0000m	-500.0000m	-500.0000m	500.0000m	-500.0000m	-500.0000m
vdsat	114.0000m	-158.7515m	-158.7515m	110.2628m	-158.7515m	-158.7515m
beta	1.6505m	851.1104u	793.5870u	1.6970m	818.6838u	793.5870u
gam eff	500.0000m	500.0000m	500.0000m	500.0000m	500.0000m	500.0000m
gm	188.1553u	135.1150u	125.9831u	187.1211u	129.9672u	125.9831u
gds	1.0108u	1.3651u	1.3651u	945.6129n	1.3651u	1.3651u
gmb	60.7269u	43.6082u	40.6609u	60.3931u	41.9467u	40.6609u
cdtot	1.7766f	1.6767f	1.7661f	1.7189f	1.7222f	1.7661f
cgtot	5.3870f	5.3870f	5.3870f	5.3870f	5.3870f	5.3870f
cstot	5.2910f	5.2910f	5.2910f	5.2910f	5.2910f	5.2910f
cbtot	1.8246f	1.7247f	1.8141f	1.7669f	1.7702f	1.8141f
cgs	4.3150f	4.3150f	4.3150f	4.3150f	4.3150f	4.3150f
cgd	1.0000f	1.0000f	1.0000f	1.0000f	1.0000f	1.0000f

```
 ******   pole/zero analysis              tnom=  25.000 temp=  25.000
******

    input =  0:vin                  output = v(out

    poles (rad/sec)                 poles ( hertz)
***********************************************************************
  real              imag            real              imag
 -25.0082x          0.              -3.9802x          0.
  -4.2458g          0.            -675.7327x          0.
 -13.3910g          0.              -2.1312g          0.
 -19.9427g          0.              -3.1740g          0.
    zeros (rad/sec)                 zeros ( hertz)
***********************************************************************
  real              imag            real              imag
 -12.0822g          0.              -1.9229g          0.
 -12.0822g          0.              -1.9229g          0.
```

poles for $C_{LOAD} = 0$ pF

```
******
cload  out 0 10p             * change the load to 10 pf

.end

***** operating point status is all       simulation time is     0.
   node      =voltage       node     =voltage       node     =voltage

+0:1         = 610.2628m 0:2        =    1.1412  0:3        =    1.1412
+0:out       = 909.5851m 0:vdd      =    1.8000  0:vin      = 614.0000m

**** mosfets

subckt
element   0:m1        0:m2        0:m3        0:m4        0:m5        0:m6
model     0:nch       0:pch       0:pch       0:nch       0:pch       0:pch
 id        10.7249u  -10.7249u  -10.0000u   10.3162u  -10.3162u  -10.0000u
```

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ibs	0.	0.	0.	0.	0.	0.
ibd	-6.1026f	11.8974f	6.5875f	-9.0959f	8.9041f	6.5875f
vgs	614.0000m	-658.7515m	-658.7515m	610.2628m	-658.7515m	-658.7515m
vds	610.2628m	-1.1897	-658.7515m	909.5851m	-890.4149m	-658.7515m
vbs	0.	0.	0.	0.	0.	0.
vth	500.0000m	-500.0000m	-500.0000m	500.0000m	-500.0000m	-500.0000m
vdsat	114.0000m	-158.7515m	-158.7515m	110.2628m	-158.7515m	-158.7515m
beta	1.6505m	851.1104u	793.5870u	1.6970m	818.6838u	793.5870u
gam eff	500.0000m	500.0000m	500.0000m	500.0000m	500.0000m	500.0000m
gm	188.1553u	135.1150u	125.9831u	187.1211u	129.9672u	125.9831u
gds	1.0108u	1.3651u	1.3651u	945.6129n	1.3651u	1.3651u
gmb	60.7269u	43.6082u	40.6609u	60.3931u	41.9467u	40.6609u
cdtot	1.7766f	1.6767f	1.7661f	1.7189f	1.7222f	1.7661f
cgtot	5.3870f	5.3870f	5.3870f	5.3870f	5.3870f	5.3870f
cstot	5.2910f	5.2910f	5.2910f	5.2910f	5.2910f	5.2910f
cbtot	1.8246f	1.7247f	1.8141f	1.7669f	1.7702f	1.8141f
cgs	4.3150f	4.3150f	4.3150f	4.3150f	4.3150f	4.3150f
cgd	1.0000f	1.0000f	1.0000f	1.0000f	1.0000f	1.0000f

****** pole/zero analysis tnom= 25.000 temp= 25.000
******

input = 0:vin output = v(out

poles (rad/sec) poles (hertz)

real	imag	real	imag
-229.1634k	0.	-36.4725k	0.
-241.2804x	0.	-38.4010x	0.
-12.0835g	0.	-1.9232g	0.
-13.7116g	0.	-2.1823g	0.

poles for C_{LOAD} = 10pF

zeros (rad/sec) zeros (hertz)

real	imag	real	imag
-12.0822g	0.	-1.9229g	0.
-12.0822g	0.	-1.9229g	0.

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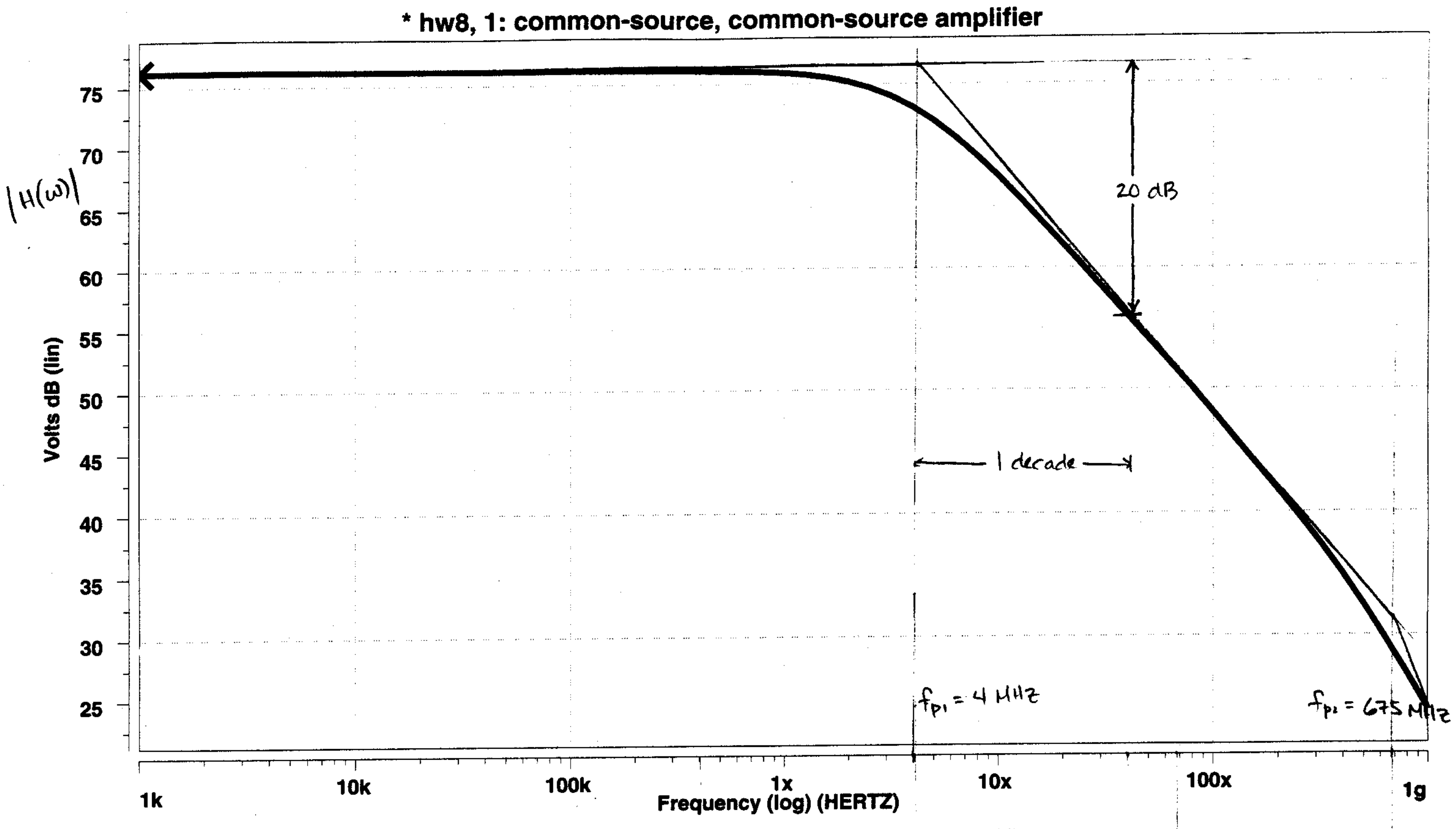
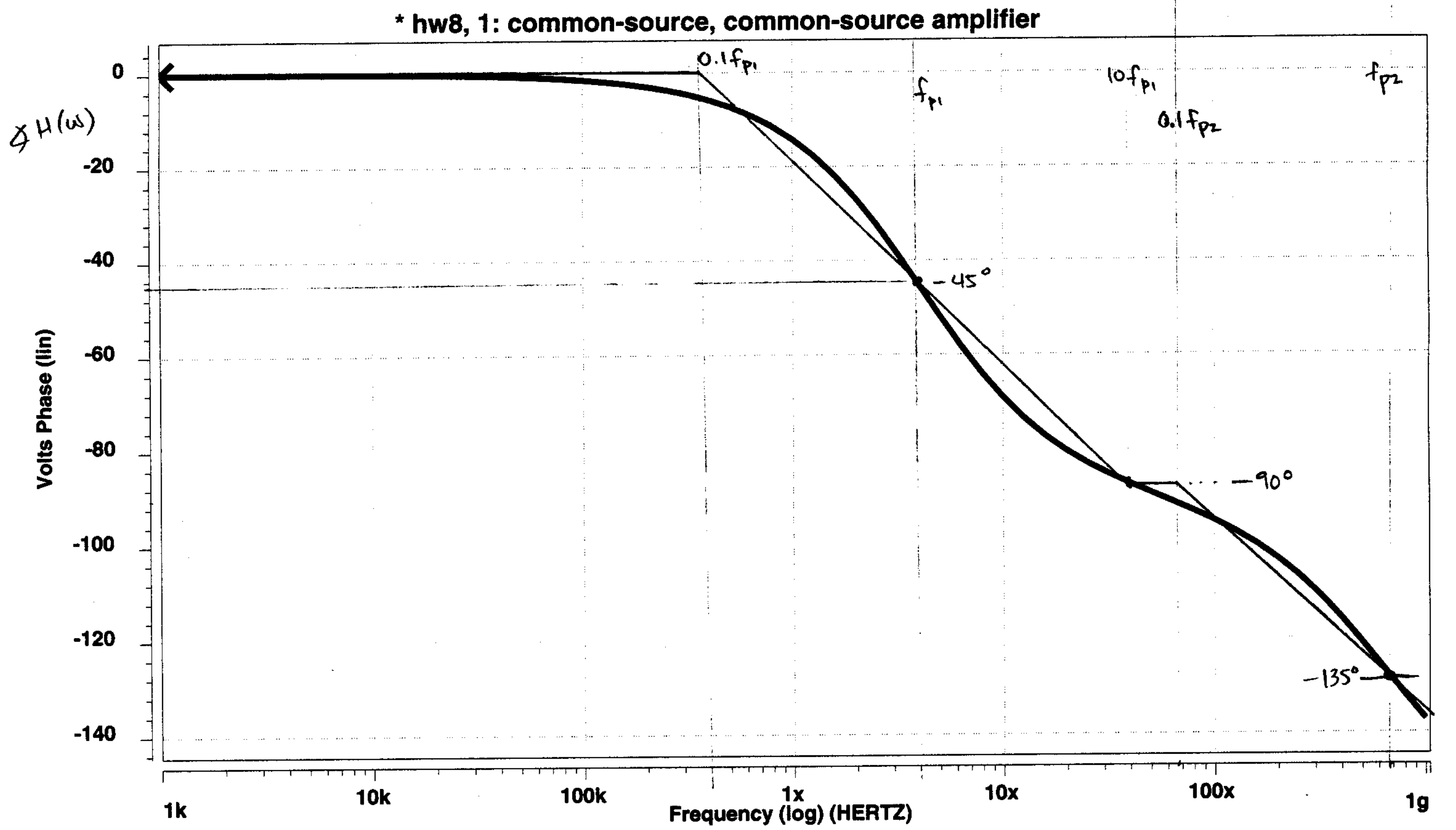
$C_{LOAD} = 0pF$





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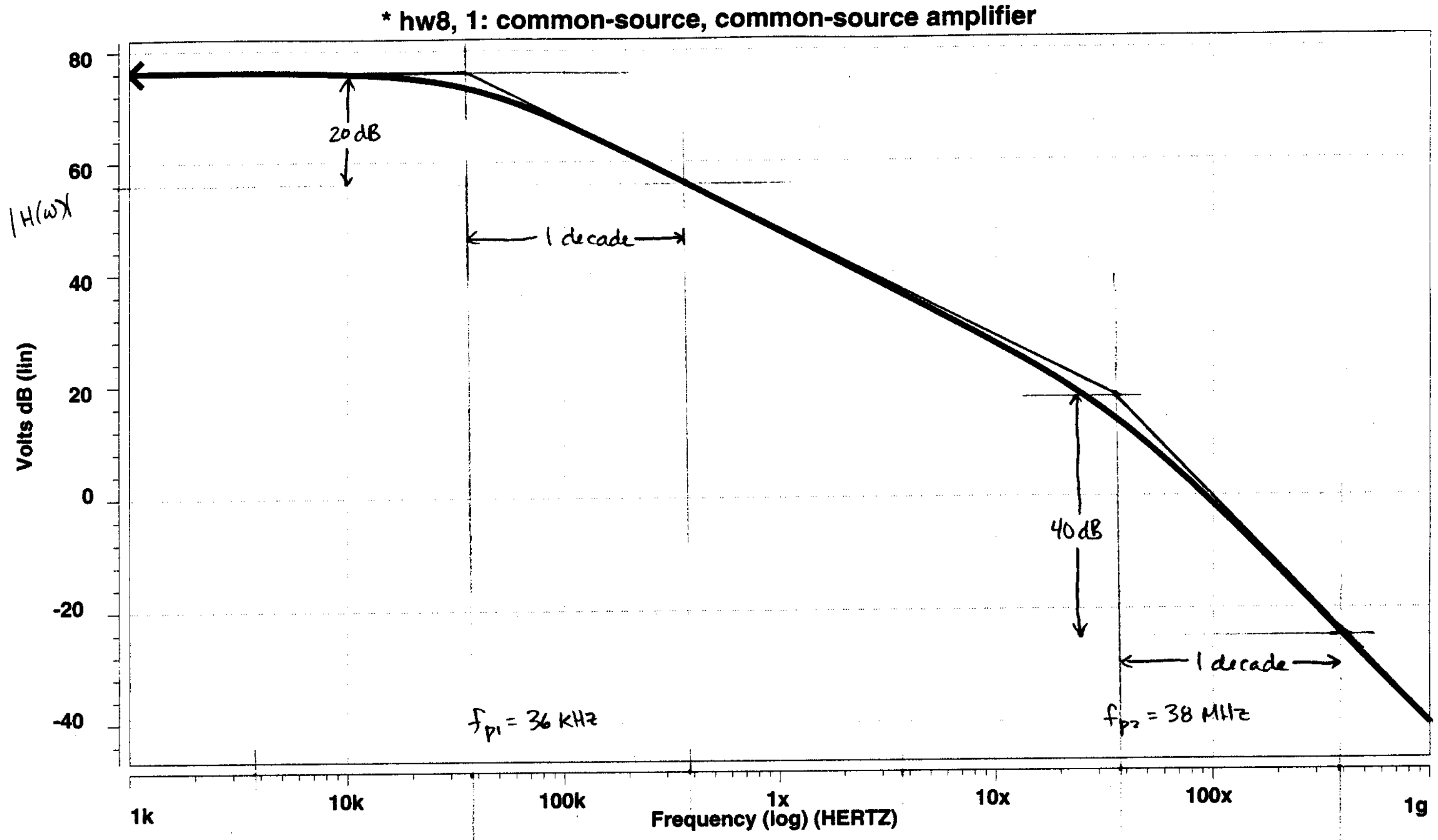
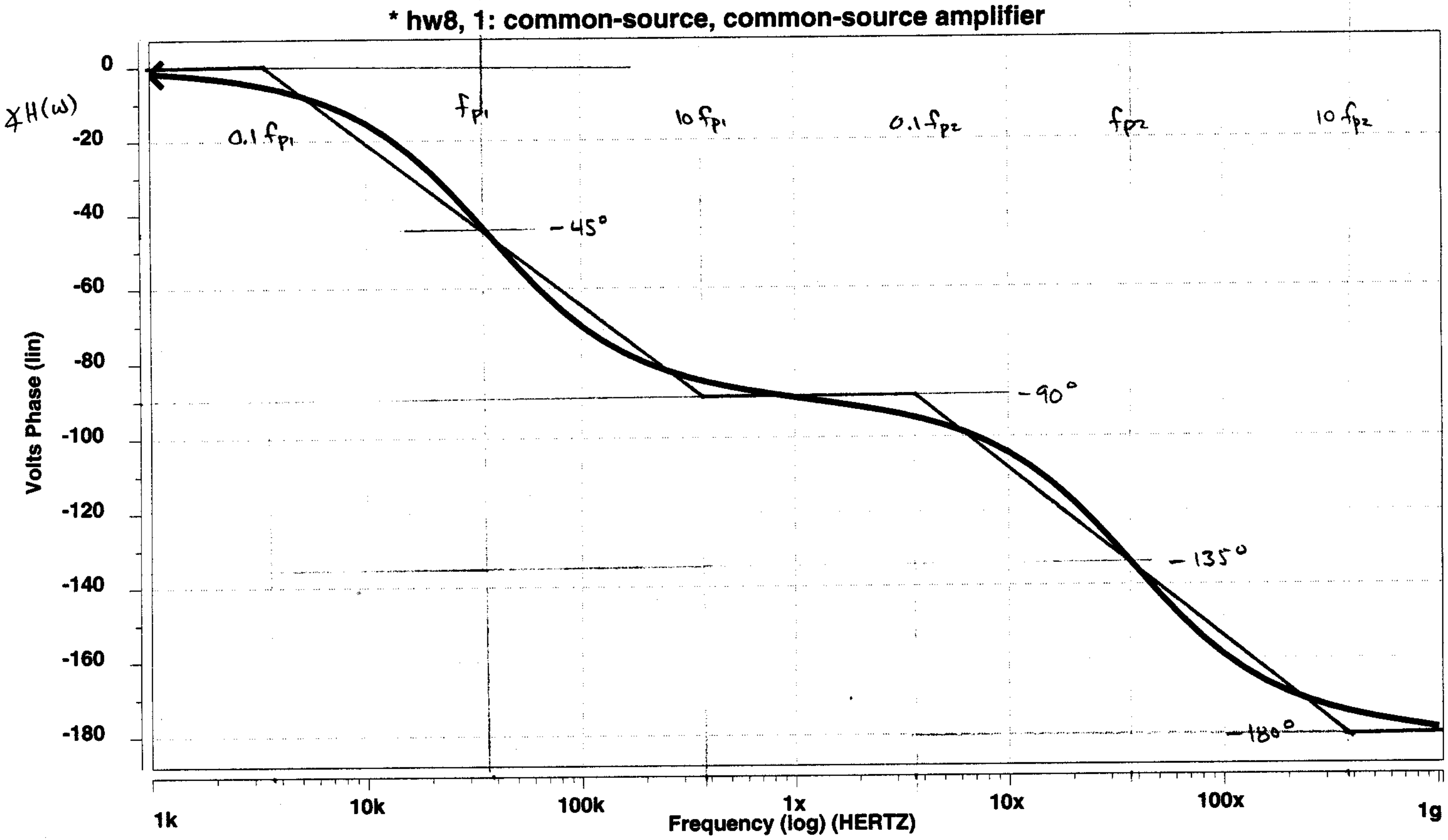
$C_{LOAD} = 10\ pF$





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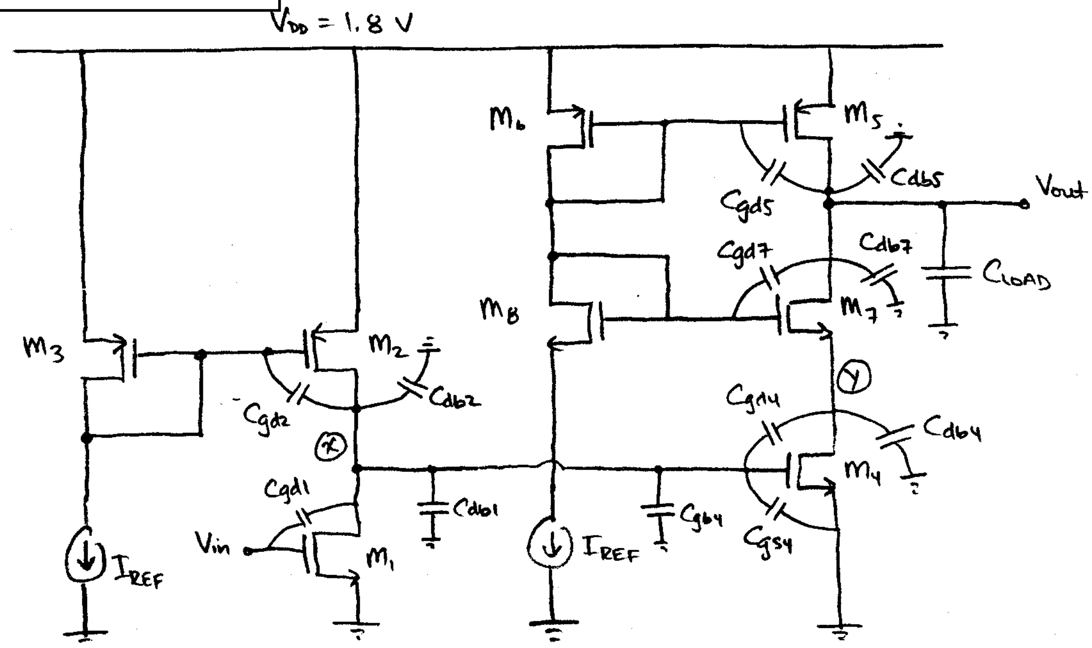
2)



a) The two poles will be associated with node x and the output. Due to the common-gate configuration of M_7, the impedance at node Y is very small, so this is not one of the first two poles.

$R_x = 400\ k\Omega$ | $R_{out} \approx r_{o5} = 666\ k\Omega$

This is very similar to the previous problem, except the large Miller capacitance is no longer present due to the common-gate stage.

$$\omega_{p1} = \frac{1}{R_x\left(C_{gd1} + C_{db1} + C_{gd2} + C_{db2} + C_{gb4} + C_{gs4} + \left(1 + g_m\left(\frac{r_{o5}+r_{o7}}{1+g_m r_{o7}}\right)\right)C_{gd4}\right)}$$

$$= \frac{1}{(400\,k\Omega \times (1 + 0.775 + 1 + 0.676 + 0.072 + 4.36 + (1 + 1 + \frac{0.1}{0.15})(1))\ fF)}$$

$= 236$ Mrad/s $\Rightarrow$ 37.7 MHz

$$\omega_{p2} = \frac{1}{R_{out}\left(C_{gd5} + C_{db5} + C_{gd7} + C_{db7}\right)}$$

$$= \frac{1}{(666k \times (1 + 0.719 + 1 + 0.719))} = 436 \text{ Mrad/s} \Rightarrow 69 \text{ MHz}$$

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2) a) (cont.)

From hand calculations,	$f_{p1} = 37.7$ MHz $f_{p2} = 69$ MHz.
From SPICE:	$f_{p1} = 32$ MHz $f_{p2} = 44$ MHz

These values are relatively close. The main discrepancy is due to the incorrect values for r_o, and assuming that the capacitors going to nodes with impedance $\frac{1}{g_m}$ actually go to ground.

c) When $C_{LOAD} = 10$ pF, the dominant pole is at the output, and the pole associated with node x does not change much.

$$\omega_{p1} = \frac{1}{R_{out} C_{LOAD}} = \frac{1}{(666\ k\Omega)(10\ pF)} = 150\ Mrad/s \Rightarrow \boxed{24\ kHz}$$

$$\omega_{p2} = \frac{1}{R_x(C_{gd1} + C_{db1} + C_{gd2} + C_{db2} + C_{gb4} + C_{gs4} + 2C_{gd4})}$$

$$= 230\ Mrad/s \Rightarrow \boxed{36.5\ MHz}$$

From hand calculations:	$f_{p1} = 24$ kHz $f_{p2} = 36.5$ MHz
From SPICE:	$f_{p1} = 22$ MHz $f_{p2} = 35$ MHz

These values are pretty close

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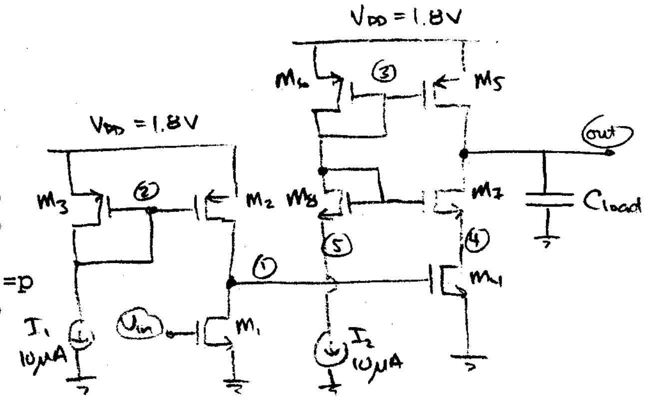
```
* hw8, 2: common-source, common-source amplifier with cascode

.model nch nmos level=1 tox=25 vto=0.5 kp=140e-6 lambda=0.1 gamma=0.5 phi=0.6
+capop=0 cgso=5e-10 cgdo=5e-10 cgbo=4e-10 cj=6e-4 cjsw=2e-10

.model pch pmos level=1 tox=25 vto=-0.5 kp=65e-6 lambda=0.15 gamma=0.5 phi=0.6
+capop=0 cgso=5e-10 cgdo=5e-10 cgbo=4e-10 cj=6e-4 cjsw=2e-10

.param w = 2u
.param l = 0.18u
.param lambda = 0.09u
.param a = '4*lambda*w'
.param p = '8*lambda+w'

vdd    vdd 0 1.8

* set up ac input source
vin    vin 0 0.61397 ac 1

m1     1 vin 0 0 nch w=w l=l ad=a pd=p as=a ps=p
m2     1 2 vdd vdd pch w=w l=l ad=a pd=p as=a ps=p
m3     2 2 vdd vdd pch w=w l=l ad=a pd=p as=a ps=p
m4     3 1 0 0 nch w=w l=l ad=a pd=p as=a ps=p
m5     out 4 vdd vdd pch w=w l=l ad=a pd=p as=a ps=p
m6     4 4 vdd vdd pch w=w l=l ad=a pd=p as=a ps=p
m7     out 4 3 3 nch w=w l=l ad=a pd=p as=a ps=p
m8     4 4 5 5 nch w=w l=l ad=a pd=p as=a ps=p
i1     2 0 10u
i2     5 0 10u

cload  out 0 0p

.options post=2 nomod captab pztol=1e-4 unwrap

.meas  dc     vbias   find v(vin) when v(out)=0.9

.probe ac vdb(out) vp(out)

.op

.dc    vin 0.613 0.617 0.01m

.pz    v(out) vin

.ac    dec 10 1k 1g

.alter
```




```
 ******  operating point information      tnom=  25.000 temp=  25.000
******
***** operating point status is all       simulation time is     0.
   node     =voltage       node    =voltage       node    =voltage

+0:1        = 612.6388m 0:2        =   1.1412  0:3        = 527.5326m
+0:4        =   1.1412  0:5        = 531.1674m 0:out      = 856.5649m
+0:vdd      =   1.8000  0:vin      = 613.9700m


**** mosfets
```

Homework 5, Fall 2004

subckt						
element	0:m1	0:m2	0:m3	0:m4	0:m5	0:m6
model	0:nch	0:pch	0:pch	0:nch	0:pch	0:pch
id	10.7216u	-10.7216u	-10.0000u	10.3886u	-10.3886u	-10.0000u
ibs	0.	0.	0.	0.	0.	0.
ibd	-6.1264f	11.8736f	6.5875f	-5.2753f	9.4344f	6.5875f
vgs	613.9700m	-658.7515m	-658.7515m	612.6388m	-658.7515m	-658.7515m
vds	612.6388m	-1.1874	-658.7515m	527.5326m	-943.4351m	-658.7515m
vbs	0.	0.	0.	0.	0.	0.
vth	500.0000m	-500.0000m	-500.0000m	500.0000m	-500.0000m	-500.0000m
vdsat	113.9700m	-158.7515m	-158.7515m	112.6388m	-158.7515m	-158.7515m
beta	1.6509m	850.8530u	793.5870u	1.6376m	824.4277u	793.5870u
gam eff	500.0000m	500.0000m	500.0000m	500.0000m	500.0000m	500.0000m
gm	188.1479u	135.0742u	125.9831u	184.4591u	130.8791u	125.9831u
gds	1.0103u	1.3651u	1.3651u	986.8052n	1.3651u	1.3651u
gmb	60.7245u	43.5950u	40.6609u	59.5339u	42.2410u	40.6609u
cdtot	1.7760f	1.6770f	1.7661f	1.7956f	1.7133f	1.7661f
cgtot	5.3870f	5.3870f	5.3870f	5.3870f	5.3870f	5.3870f
cstot	5.2910f	5.2910f	5.2910f	5.2910f	5.2910f	5.2910f
cbtot	1.8240f	1.7250f	1.8141f	1.8436f	1.7613f	1.8141f
cgs	4.3150f	4.3150f	4.3150f	4.3150f	4.3150f	4.3150f
cgd	1.0000f	1.0000f	1.0000f	1.0000f	1.0000f	1.0000f

subckt		
element	0:m7	0:m8
model	0:nch	0:nch
id	10.3886u	10.0000u
ibs	0.	0.
ibd	-3.2903f	-6.1008f
vgs	613.7160m	610.0811m
vds	329.0323m	610.0811m
vbs	0.	0.
vth	500.0000m	500.0000m
vdsat	113.7160m	110.0811m
beta	1.6067m	1.6505m
gam eff	500.0000m	500.0000m
gm	182.7118u	181.6842u
gds	1.0058u	942.4997n
gmb	58.9700u	58.6383u
cdtot	1.8492f	1.7766f
cgtot	5.3870f	5.3870f
cstot	5.2910f	5.2910f
cbtot	1.8972f	1.8246f
cgs	4.3150f	4.3150f
cgd	1.0000f	1.0000f

****** pole/zero analysis tnom= 25.000 temp= 25.000
******

input = 0:vin output = v(out

poles (rad/sec) poles (hertz)

****

real	imag	real	imag
-205.7070x	0.	-32.7393x	0.
-276.3565x	0.	-43.9835x	0.
-13.0711g	0.	-2.0803g	0.
-20.8381g	0.	-3.3165g	0.
-25.3158g	0.	-4.0291g	0.

zeros (rad/sec) zeros (hertz)

poles for $C_{load} = 0\,pF$

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```
************************************************************************
   real              imag              real              imag
 -12.0822g           0.              -1.9229g            0.
 -18.9192g           0.              -3.0111g            0.


******
cload  out 0 10p               * change the load to 10 pf

.end

 ******  operating point information      tnom=  25.000 temp=  25.000
******
***** operating point status is all       simulation time is     0.
   node     =voltage      node     =voltage      node     =voltage

+0:1        = 612.6388m 0:2        =   1.1412  0:3        = 527.5326m
+0:4        =   1.1412  0:5        = 531.1674m 0:out      = 856.5649m
+0:vdd      =   1.8000  0:vin      = 613.9700m


**** mosfets

subckt
element  0:m1        0:m2        0:m3        0:m4        0:m5        0:m6
model    0:nch       0:pch       0:pch       0:nch       0:pch       0:pch
 id        10.7216u  -10.7216u  -10.0000u    10.3886u  -10.3886u  -10.0000u
 ibs        0.         0.         0.          0.         0.         0.
 ibd       -6.1264f   11.8736f    6.5875f    -5.2753f    9.4344f    6.5875f
 vgs      613.9700m -658.7515m -658.7515m  612.6388m -658.7515m -658.7515m
 vds      612.6388m   -1.1874   -658.7515m  527.5326m -943.4351m -658.7515m
 vbs        0.         0.         0.          0.         0.         0.
 vth      500.0000m -500.0000m -500.0000m  500.0000m -500.0000m -500.0000m
 vdsat    113.9700m -158.7515m -158.7515m  112.6388m -158.7515m -158.7515m
 beta       1.6509m  850.8530u  793.5870u    1.6376m  824.4277u  793.5870u
 gam eff  500.0000m  500.0000m  500.0000m  500.0000m  500.0000m  500.0000m
 gm       188.1479u  135.0742u  125.9831u  184.4591u  130.8791u  125.9831u
 gds        1.0103u    1.3651u    1.3651u  986.8052n    1.3651u    1.3651u
 gmb       60.7245u   43.5950u   40.6609u   59.5339u   42.2410u   40.6609u
 cdtot      1.7760f    1.6770f    1.7661f    1.7956f    1.7133f    1.7661f
 cgtot      5.3870f    5.3870f    5.3870f    5.3870f    5.3870f    5.3870f
 cstot      5.2910f    5.2910f    5.2910f    5.2910f    5.2910f    5.2910f
 cbtot      1.8240f    1.7250f    1.8141f    1.8436f    1.7613f    1.8141f
 cgs        4.3150f    4.3150f    4.3150f    4.3150f    4.3150f    4.3150f
 cgd        1.0000f    1.0000f    1.0000f    1.0000f    1.0000f    1.0000f

subckt
element  0:m7        0:m8
model    0:nch       0:nch
 id        10.3886u   10.0000u
 ibs        0.         0.
 ibd       -3.2903f   -6.1008f
 vgs      613.7160m  610.0811m
 vds      329.0323m  610.0811m
 vbs        0.         0.
 vth      500.0000m  500.0000m
 vdsat    113.7160m  110.0811m
 beta       1.6067m    1.6505m
 gam eff  500.0000m  500.0000m
```

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```
gm         182.7118u  181.6842u
gds          1.0058u  942.4997n
gmb         58.9700u   58.6383u
cdtot        1.8492f    1.7766f
cgtot        5.3870f    5.3870f
cstot        5.2910f    5.2910f
cbtot        1.8972f    1.8246f
cgs          4.3150f    4.3150f
cgd          1.0000f    1.0000f


 ******   pole/zero analysis            tnom=  25.000 temp=  25.000
******

     input =   0:vin                   output = v(out

     poles (rad/sec)                   poles ( hertz)
***********************************************************************
   real              imag              real              imag
-136.9762k           0.             -21.8004k            0.
-217.4785x           0.             -34.6128x            0.
 -12.1375g        -690.5360x         -1.9317g        -109.9022x
 -12.1375g         690.5360x         -1.9317g         109.9022x
 -26.4176g           0.              -4.2045g            0.
     zeros (rad/sec)                   zeros ( hertz)
***********************************************************************
   real              imag              real              imag
 -12.0822g           0.              -1.9229g            0.
 -18.9192g           0.              -3.0111g            0.
```

poles for C_{load} = 10pF

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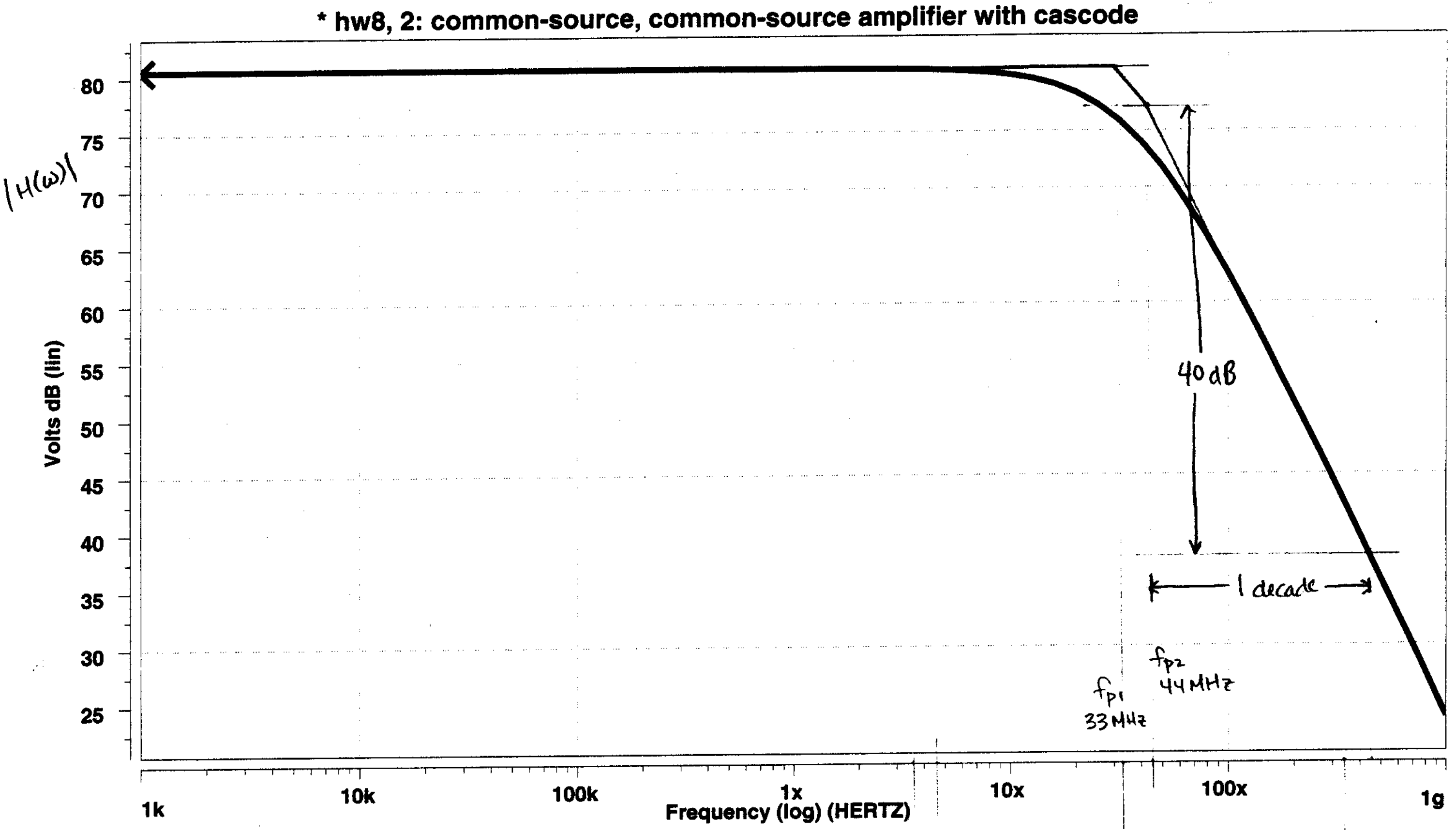
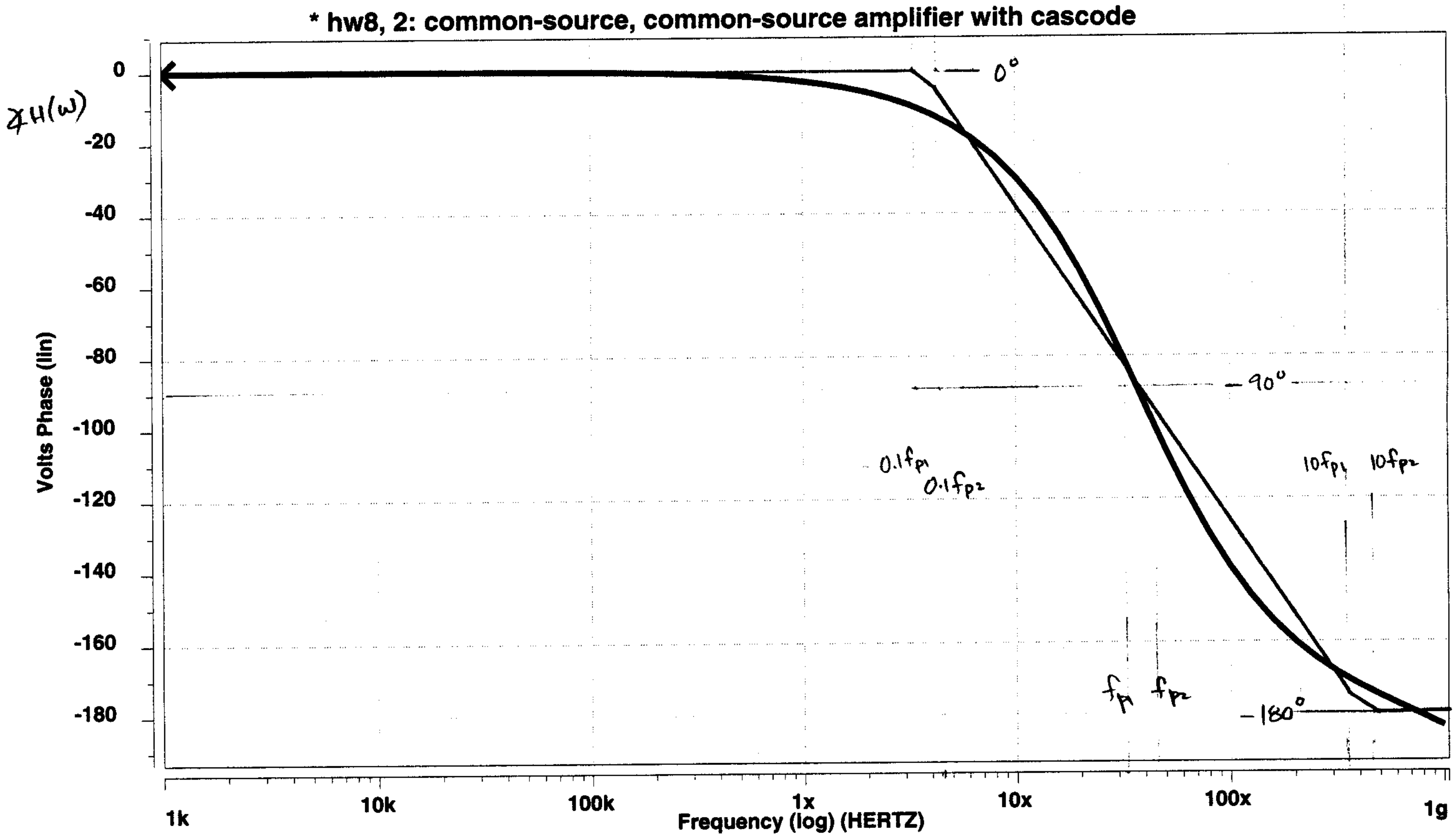
Cload = 0pF





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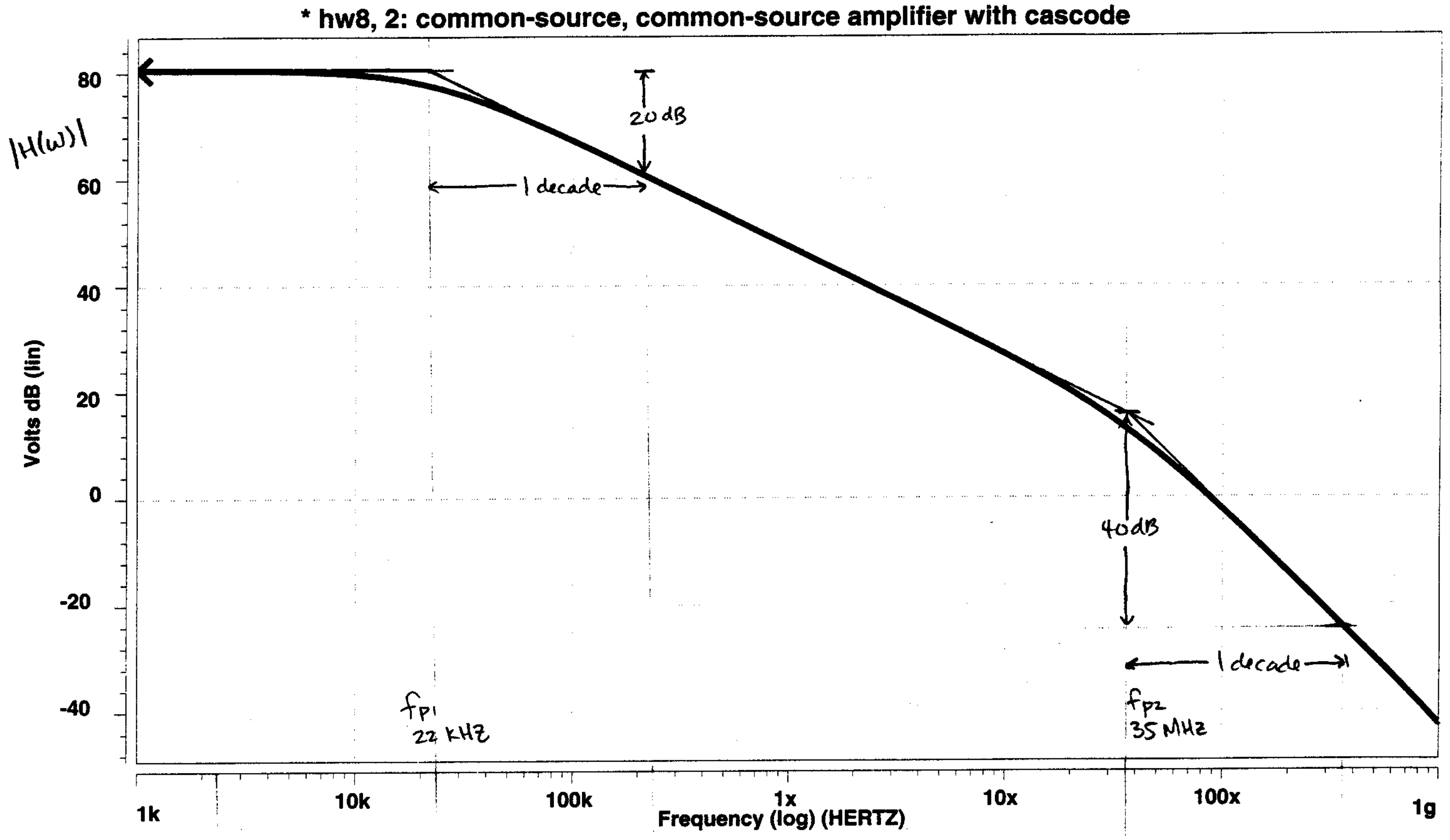
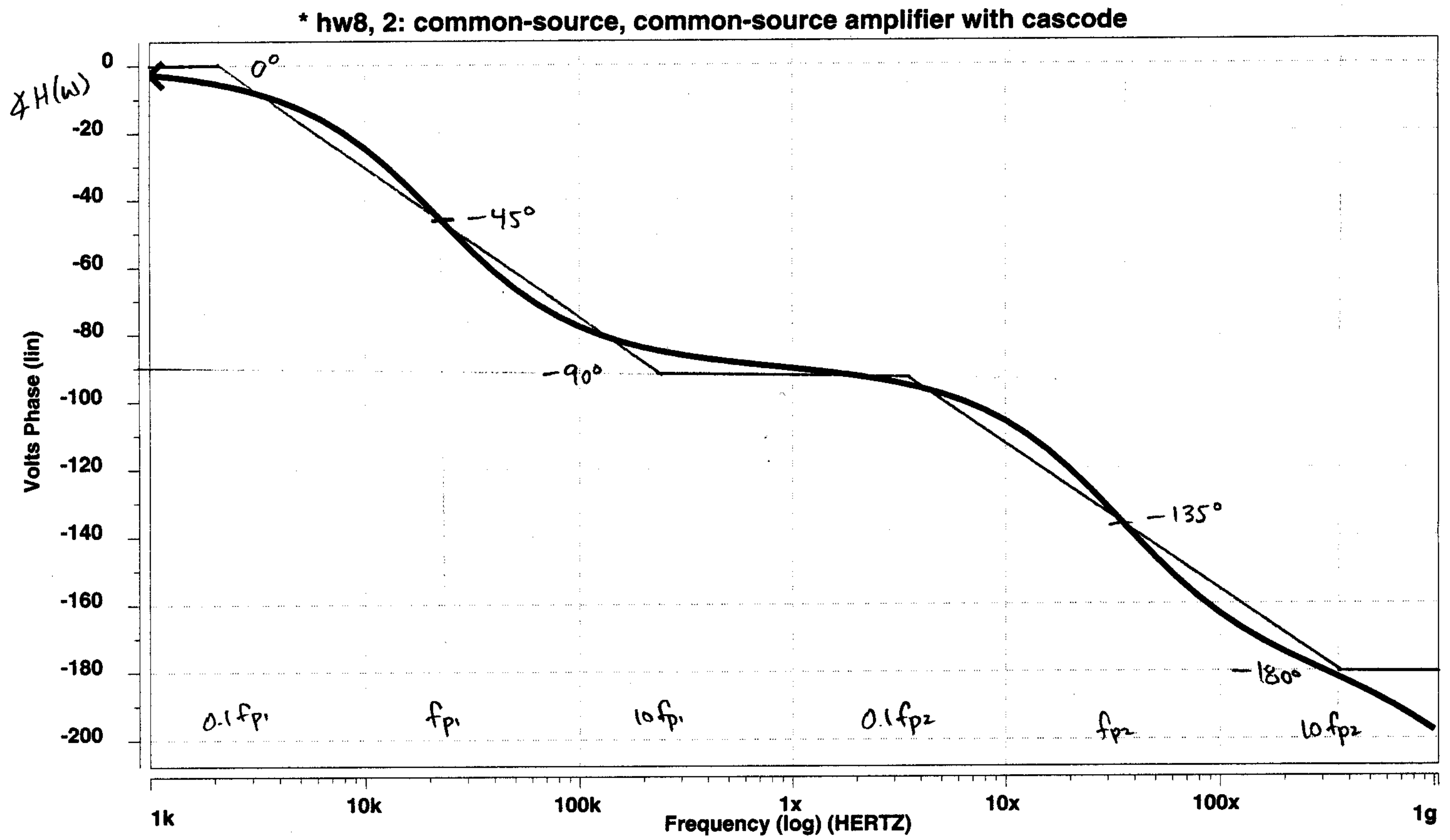
$C_{LOAD} = 10pF$





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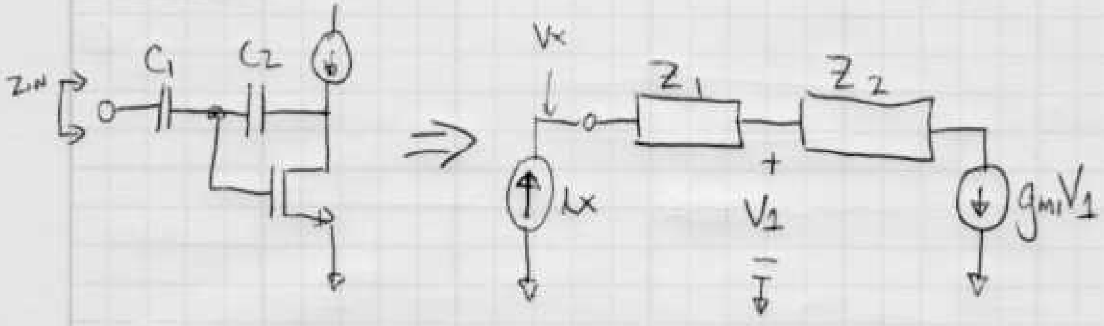
6.6 a



$$Z_1 = \frac{1}{j\omega C_1}$$

$$Z_2 = \frac{1}{j\omega C_2}$$

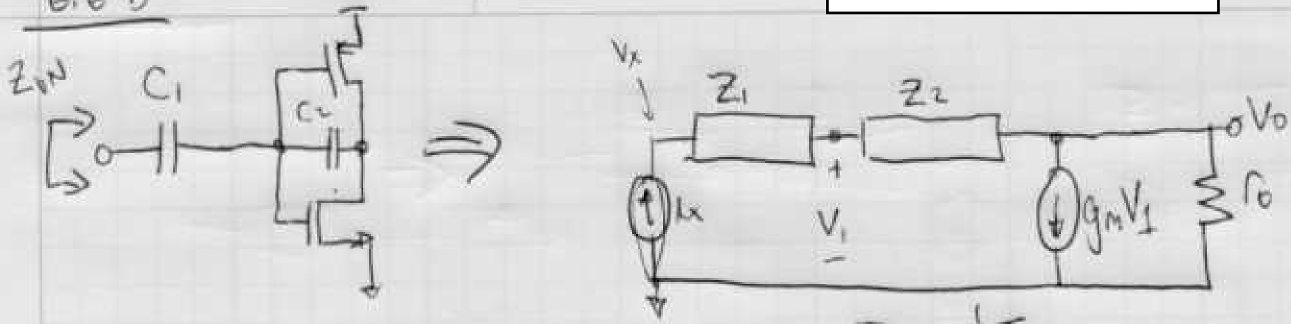
(1) $i_x = g_{m1}V_1 \Rightarrow V_1 = \frac{i_x}{g_{m1}}$

(2) $V_x = V_1 + i_x \cdot Z_1$

$\Rightarrow V_x = i_x\left(\frac{1}{g_{m1}} + Z_1\right)$

$$Z_{IN} = \frac{V_x}{i_x} = \frac{1}{g_{m1}} + Z_1 = \frac{1}{g_{m1}} + \frac{1}{j\omega C_1} = \frac{j\omega C_1 + g_{m1}}{g_{m1}(j\omega C_1)}$$

6.6 b



$$Z_1 = \frac{1}{j\omega C_1}$$

$$Z_2 = \frac{1}{j\omega C_2}$$

$$g_m = g_{m1} + g_{m2}$$

$$r_o = r_{o1} \| r_{o2}$$

$$i_x = g_m V_1 + \frac{V_o}{r_o} \qquad (1)$$

$$V_x = V_1 + i_x \cdot Z_1 \qquad (2)$$

$$V_1 = V_o + i_x Z_2 \qquad (3)$$

$$(1+2) \Rightarrow i_x = g_m (V_x - i_x Z_1) + \frac{V_o}{r_o}$$

$$\Rightarrow i_x = g_m V_x - g_m Z_1 V_x + \frac{V_o}{r_o} \qquad (4)$$

$$(2+3) \Rightarrow V_o = V_x - i_x (Z_1 + Z_2) \qquad (5)$$

$$(4+5) \Rightarrow i_x = g_m V_x - g_m Z_1 i_x + \frac{V_x}{r_o} - i_x \frac{Z_1 + Z_2}{r_o}$$

$$\Rightarrow i_x \left(1 + g_m Z_1 + \frac{Z_1 + Z_2}{r_o}\right) = V_x \left(g_m + \frac{1}{r_o}\right) \qquad (6)$$

$$Z_{IN} \triangleq \frac{V_x}{i_x} = \frac{1 + g_m Z_1 + \frac{Z_1 + Z_2}{r_o}}{g_m + \frac{1}{r_o}} =$$

$$\boxed{Z_{IN} = \frac{1 + \frac{g_{m1} + g_{m2}}{j\omega C_1} + \frac{1}{(r_{o1} \| r_{o2}) j\omega C_1} + \frac{1}{(r_{o1} \| r_{o2}) j\omega C_2}}{(g_{m1} + g_{m2}) + \frac{1}{r_{o1} \| r_{o2}}}}$$

6.6c

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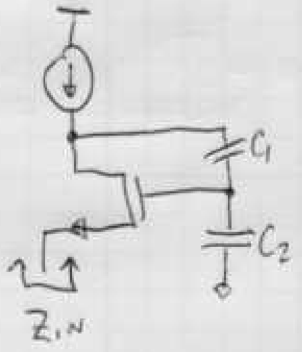
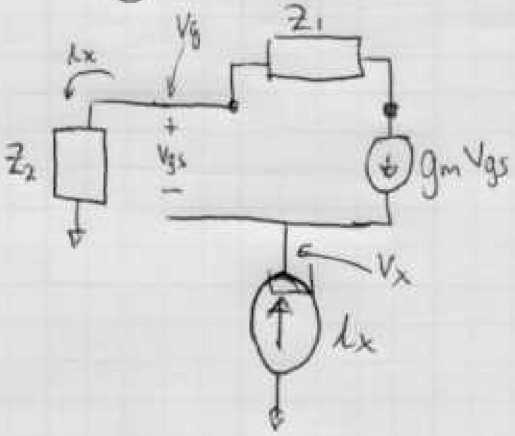


$\Rightarrow$

Assume $\gamma = 0$



$$Z_1 = \frac{1}{j\omega C_1}$$

$$Z_2 = \frac{1}{j\omega C_2}$$

① $i_x = -g_m V_{gs}$

② $V_x + V_{gs} = V_g$

③ $V_g = i_x Z_2$

(2+3) $\Rightarrow V_x + V_{gs} = i_x Z_2$ ④

(4+1) $\Rightarrow V_x - \frac{i_x}{g_m} = i_x Z_2$

$$\Rightarrow V_x = i_x\left(\frac{1}{g_m} + Z_2\right)$$

$$Z_{IN} = \frac{V_x}{i_x} = \frac{1}{g_m} + Z_2 = \frac{1}{g_m} + \frac{1}{j\omega C_2}$$